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THE BIOCLIMATIC LAW AS APPLIED TO ENTOMOLOGICAL RESEARCH AND FARM PRACTISE

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IN CHARGE OF BRANCH OF FOREST ENTOMOLOGY, BUREAU OF ENTOMOLOGY

THE best success in entomological research, carried on with the view of advancing scientific knowledge and determining facts of practical value to agricultural pursuits, is founded on fundamental laws and principles which govern the seasonal activities and geographical distribution of the species of insects studied. Success in farm practise may be and is attained without any recognized knowledge on the part of the farmer of the laws that govern the results of a given farm practise, but at the same time there are many failures which certainly could be prevented through his recognition of some of the fundamental as well as general features of such laws.

It is, therefore, one of the missions of scientific research to reveal and explain the natural laws that govern certain human activities and to point out how success may be attained and failure avoided through a proper interpretation and application of the information thus acquired and disseminated.

We have in the so-called bioclimatic law of latitude, longitude and altitude[1] an example of a natural law which represents the general laws of climate as affecting the seasonal activities and geographical distribution of land-inhabiting species of plants and animals, periodical practise in agriculture, and the adaptation of farm crops to the requirements of climatic conditions. The law is founded on the determined country-wide average rate of variation in the time at which periodical events occur in the seasonal development and habits of plants and animals at different geographical positions within the range of their distribution. Other things being equal, this variation is at the rate of four days for each degree of latitude, five degrees of longitude and 400 feet of altitude. Therefore, from any given place, as related to extensive regions, an entire country, or a continent, the variation in a given periodical event is (at the rate stated) later northward, eastward and upward in the spring and early summer and the reverse in the late summer and during autumn.

[1] Supplement 9, *Monthly Weather Review*, 1918.

For example, if the date of an event in the spring is March 15 at a given place, the same event should occur, under average conditions at the same altitude, four days later (March 19) at a place one degree north, five degrees east, or 400 feet higher. In the opposite directions it should have occurred four days earlier (March 11) at a place one degree south, five degrees west, or 400 feet lower, while at a place one degree south, five degrees west, and 400 feet lower, the date should have occurred four days earlier for latitude, four days earlier for longitude and four days earlier for altitude or a total of twelve days earlier (March 3).

In like manner, if the date of an autumn event is September 15, the corresponding date for the same event, at a place one degree north, five degrees east, or 400 feet higher, should have been September 11, or four days earlier. In the opposite directions it would be four days later (September 19), while at a place one degree south, five degrees west, and 400 feet lower, it would be twelve days later (September 27). In a like manner the rate of variation in time is the same with any given combination of latitude, longitude and altitude, provided other conditions are equal. We know, however, that conditions as to topography, exposure, prevailing winds, sunshine, rain, etc., are rarely, if ever, equal in two or more regions and, even at different places within a restricted locality, the topography, character of soil, air drainage and other minor influences on life activities may be quite different. We must expect, therefore, to find, and do find, a greater or less departure of the actual from the computed date of a periodical event for a given place.

The amount of the departure of the actual from the computed date is found to be in direct proportion to the intensity of the controlling influences. Therefore the date, as computed from the time coordinates of the law, serves as a constant by which the intensity of the influences which cause the departure can be measured in terms of days or the equivalent in degrees of latitude or feet of altitude.[2]

Thus a date in the spring, four days earlier than the computed constant, represents, as a rule, an accelerating influence equal to four days' advance of the season or the conditions to be found one degree south or at 400 feet lower altitude; on the other hand, a date in the spring four days later than the computed constant would represent a retarding influence equal to four days' retardation of the season or the conditions that occur

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[2] Four days of time equal, according to the law, one degree of latitude or 400 feet of altitude.

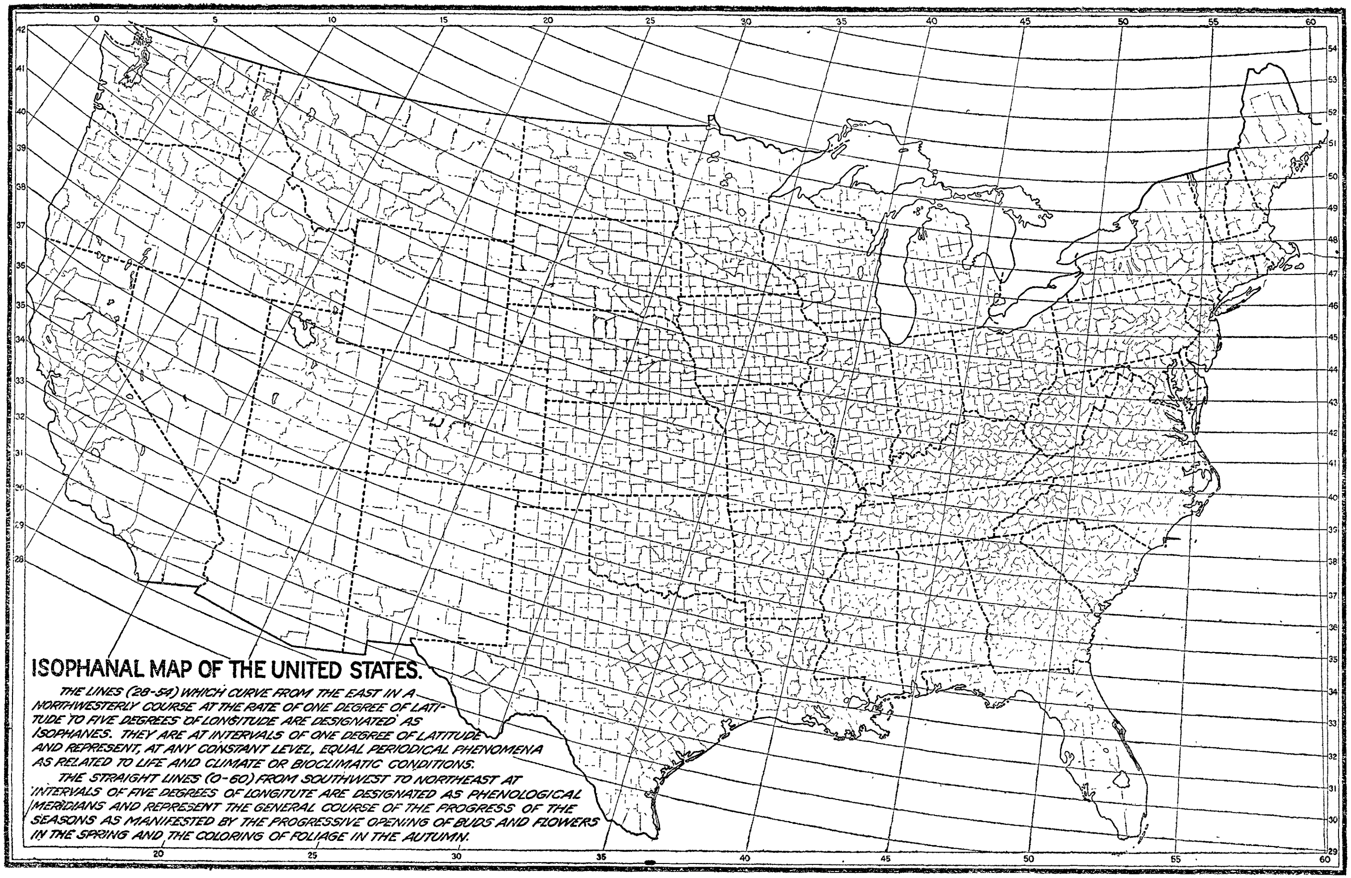
ISOPHANAL MAP OF THE UNITED STATES.
THE LINES (28-54) WHICH CURVE FROM THE EAST IN A NORTHWESTERLY COURSE AT THE RATE OF ONE DEGREE OF LATITUDE TO FIVE DEGREES OF LONGITUDE ARE DESIGNATED AS ISOPHANES. THEY ARE AT INTERVALS OF ONE DEGREE OF LATITUDE AND REPRESENT, AT ANY CONSTANT LEVEL, EQUAL PERIODICAL PHENOMENA AS RELATED TO LIFE AND CLIMATE OR BIOCLIMATIC CONDITIONS.
THE STRAIGHT LINES (0-60) FROM SOUTHWEST TO NORTHEAST AT INTERVALS OF FIVE DEGREES OF LONGITUTE ARE DESIGNATED AS PHENOLOGICAL MERIDIANS AND REPRESENT THE GENERAL COURSE OF THE PROGRESS OF THE SEASONS AS MANIFESTED BY THE PROGRESSIVE OPENING OF BUDS AND FLOWERS IN THE SPRING AND THE COLORING OF FOLIAGE IN THE AUTUMN.

FIG. 1. ISOPHANAL MAP OF THE UNITED STATES IN 1 DEGREE ISOPHANES and 1 × 5 degree quadrangles to illustrate method of expressing the geographical constants of the Law.

one degree farther north or at an altitude 400 feet greater. In the autumn an earlier date would represent an influence equal to that which would cause four days' advance in autumn conditions, whereas a later date would represent an influence equal to that which would cause four days' delay and, in a like manner, the intensity of the influences would be measured in days of time or their equivalent in latitude or altitude. See Fig. 2 for estimated spring and autumn departures for phenological quadrangles.

It will be seen from the foregoing that from the date of a periodical event or practise at an established base[3] in any given season we can, by means of the time constants of the law and their equivalents in latitude, longitude and altitude, compute a corresponding date constant of the same event for any other place within the range of the species or periodical practise involved. Or, having determined for any section of the country the upper or northern limit in the geographical distribution of a native or introduced species or variety of animal or plant, the corresponding limit constants for altitude or latitude can be computed for any other section; and having determined also the lower or southern limit, the altitude and latitude constants can be worked out for the possible geographical range in which the species or variety, under its other environmental requirements, would survive and thrive.

With the time, altitude and latitude constants determined in this manner and the rates of departure determined from recorded facts and prevailing evidences at enough representative localities to establish the general intensity of the influences which cause and maintain the departures, and with this intensity measured in terms of time, altitude or latitude as required, the constants can be corrected by adding to or subtracting from them the amount of the departure, thus closely approximating the actual.

The methods of procedure and the results attained in a study of the wheat-harvest and wheat-seeding data, as described in Supplement 9 of the Monthly Weather Review, serve to illustrate the practical application of the law to any line of biological research or farm practise which involves a consideration of geographical relations and seasonal periodicity.

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[3] A phenological base is a geographical position represented by a named place or locality where a sufficient number of observations have been made to establish corrections for local and regional influences, so that the date of any seasonal event recorded there may serve as a reliable basis for the computation of corresponding dates for the same event at any other geographical position within the same or different regions of a country or continent.

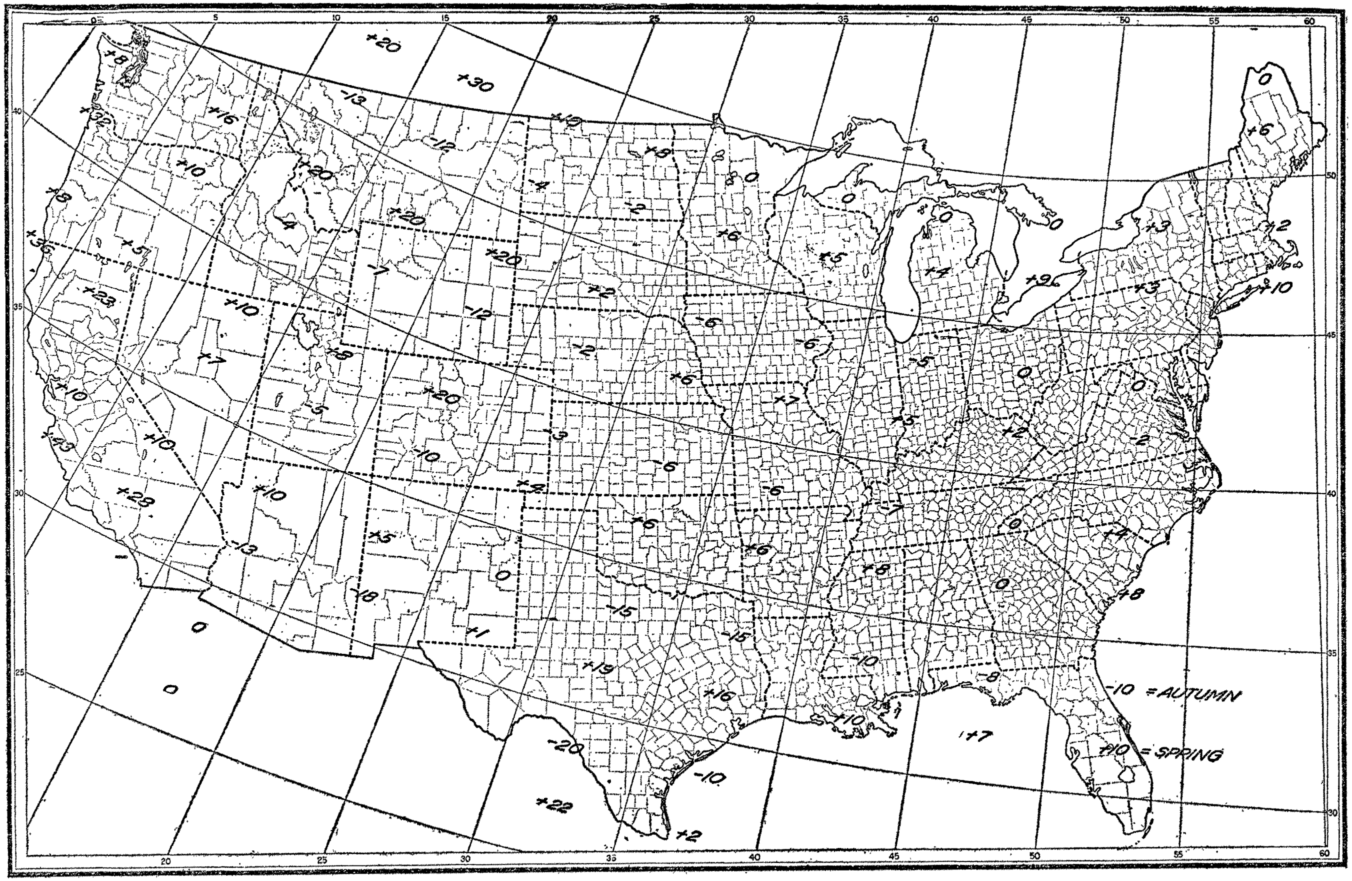


FIG. 2. ISOPHANAL MAP OF THE UNITED STATES IN 5 DEGREE ISOPHANES and 5 x 5 degree quadrangles to illustrate method of designating phenological areas for the study of influences which contribute to time, altitude or latitude departures from the geographical constants. The estimated minus (earlier) and plus (later) departures in days from the computed time constant for spring and autumn events, as given for each quadrangle, are based on a study of more than 40,000 reports on the date wheat harvest begins and on other statistics of planting and harvest dates for wheat, potatoes, etc., and represent averages for the entire quadrangle.

Isophanal maps (Fig. 1) are prepared to serve as an aid in the computation of the time, altitude and latitude constants and to facilitate the location of places, regions, etc., in connection with studies of applications of the law. (See explanation of isophanes and phenological meridians on the map.) The intervals between the isophanes in Fig. 1 represent one degree of latitude and the isophanes are numbered to correspond with the numerical designation of the parallels of latitude intersected by them on the one hundredth meridian of longitude. The course of the isophanes across the map at the rate of one degree of latitude to five degrees of longitude provides for the variation in the longitude factor of the law, so that the only factors to be considered in the computations of the constants are latitude as represented by the isophanes and the altitude as determined for any given place. Since the isophane represents the same constant or average date of a periodical phenomenon for any given level throughout its length, any variation in level will involve a variation in the time constant at the rate of one day for each 100 feet. Thus, if the date of a spring event at one place on or near isophane 40, at an altitude of 400 feet, is March 15, it should be the same date at the same altitude, four days later at 800 feet or four days earlier at sea level, at any other place on or near this isophane. Following this method, calendars of date constants are worked out from a given base date to apply to a range of altitudes along any or all of the isophanes of a map of the state, region, country or continent for which the calendar is prepared, as in Fig. 3.

To find the calendar date for any given locality on the map, determine the geographical position of the place with reference to the nearest isophane to the south of it, then determine the average altitude of the place and find the date in the calendar on the horizontal line bearing the same number as the isophane and in the altitude column giving the altitude nearest to that of the place.

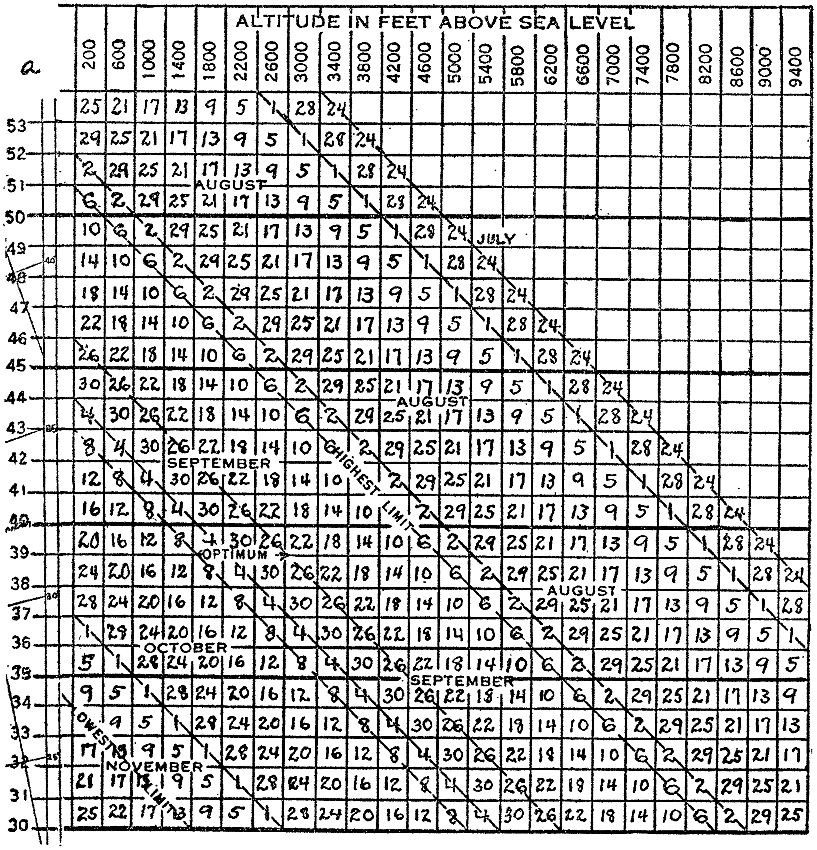
APPLICATION OF THE BIOCLIMATIC LAW TO ENTOMOLOGICAL RESEARCH

The investigations begun by the writer in 1895 which resulted in the development of facts and evidence on which the bioclimatic law is based were with the object of solving problems in forest entomology. Some of these problems were:

(*a*) The relation of the geographical distribution of forest insects to the life zones proposed by Merriam (1890 to 1894).

(*b*) The relation of variations in the seasonal or life history of forest insects to variations in geographical positions.

(*c*) The relations of critical events in the seasonal history of destructive forest insects to certain periodical events in plants, including the trees they infest, with special reference to the discovery of reliable guides in the plant events to the best time to conduct control operations against the insects at any altitude or latitude within their range.


ALTITUDE IN FEET ABOVE SEA LEVEL
a
53
52
51
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
40
35
30
25
AUGUST
JULY
AUGUST
SEPTEMBER
HIGHEST LIMIT
OPTIMUM
AUGUST
OCTOBER
SEPTEMBER
LOWEST LIMIT
NOVEMBER

200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600	5000	5400	5800	6200	6600	7000	7400	7800	8200	8600	9000	9400
25	21	17	13	9	5	1	28	24															
29	25	21	17	13	9	5	1	28	24														
2	29	25	21	17	13	9	5	1	28	24													
6	2	29	25	21	17	13	9	5	1	28	24												
10	6	2	29	25	21	17	13	9	5	1	28	24											
14	10	6	2	29	25	21	17	13	9	5	1	28	24										
18	14	10	6	2	29	25	21	17	13	9	5	1	28	24									
22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24								
26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24							
30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24						
4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24					
8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24				
12	8	4	30	26	22	18	14	10		2	29	25	21	17	13	9	5	1	28	24			
16	12	8	4	30	26	22	18	14	10		2	29	25	21	17	13	9	5	1	28	24		
20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24	
24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24
28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28
1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1
5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5
9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9
	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13
17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17
21	17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21
25	22	17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25

FIG. 3. Calendar of wheat seeding date constants for Isophanal Map Fig. 1. *a*, Isóphanes. The dates in this calendar are the computed constants for the given altitudes to be corrected for the 5×5 quadrangles of Fig. 2, by adding the + and subtracting the — autumn date which will give the general average date for the average altitude and average season.

(*d*) The devising of systems of maps and calendars by means of which the date, period, altitude or latitude constants could be shown or found for any geographical position within the range of the insect or subject involved.

(*e*) Problems *a* to *d* as related to farm, garden and fruit insects.

(*f*) The time to sow winter wheat at any given geographical position within the range of winter wheat culture to avoid serious damage by the Hessian fly.

PROGRESS TOWARDS THE SOLVING OF ENTOMOLOGICAL PROBLEMS

With regard to certain forest insects and the Hessian fly, considerable progress has been made towards solving some of the fundamental features of the problems mentioned.

The Southern Pine Beetle

The southern pine beetle (*Dendroctonus frontalis* Zimm.) is by far the most destructive enemy of southern pine timber. It is safe to say from observations and records that during the past thirty years it has killed, and otherwise been the primary cause of the destruction of, more merchantable-sized timber in the states south of Pennsylvania than all other natural agencies combined, including forest fires.

Distribution.—The normal distribution of this beetle is represented by that of the long-leaf and loblolly pines and the greater part of the range of the short-leaf or eastern yellow pine, south of Virginia and West Virginia. Its abnormal range extends through the pine areas into the spruce areas, or Canadian zone of North Carolina, West Virginia and the pine areas of southern Pennsylvania, where, under a series of years of favorable climatic conditions, it may become temporarily established, as it did during a few years preceding 1893, and become exceedingly destructive to the pine and spruce timber.

Number of Generations.—In the northern and highest limits of distribution there are not more than two complete generations of the beetle annually, but in its southern range there are five or more generations with a most complex overlapping of the broods of several generations during the late spring, summer and early fall months.

Control.—The essential requirements of control relate to a period beginning with the last active flight of the beetles in the fall and ending before flight begins in the spring.

Between the northern or highest range of distribution and near sea level along the Gulf of Mexico, the ending of the critical period for control work will vary, with latitude and altitude, from early in February along the gulf coast to the middle of May at the northern or the highest limit. In like manner the autumn period will begin in the north and at the higher altitudes in September and farther south toward sea level in December.

It is necessary to have some reliable guide as to the time for ending control operations in the spring and for beginning them again in the fall at any given place intermediate between the northern or highest and southern or lowest limits. This guide is provided through the application of the bioclimatic law in the computation of time constants and the preparation of a map calendar of control dates, so that, knowing the location of an infested area, the dates for the beginning and ending of control operations can be recommended without preliminary investigation.

The Western Pine Beetle

The western pine beetle (*Dendroctonus brevicomis* Lec.) is closely related in specific characters and habits to the southern pine beetle and is equally destructive in its attack on the western yellow pine (*Pinus ponderosa*) of the Pacific Slope and northern Rocky Mountains.

Distribution.—The distribution of this beetle is represented by the latitude and altitude range of its host tree throughout the Pacific Slope and the drainage area of the Columbia River, eastward to central Montana and Wyoming, southward into Utah and Nevada, and northward into British Columbia.

Number of Generations.—Towards the highest altitude limits there is one complete generation annually and the beginning of a second, while at lower altitudes there may be two generations annually.

Control.—The essential requirement in the control of this beetle, like that of the southern pine beetle, is to begin control operations in the fall after flight ceases and end them before general flight begins in the spring.

Owing to the zonal limits of the western yellow pine, determined as it is largely by altitude, there is not the wide range with latitude in the spring ending and fall beginning of the critical period of control that is found in the case of the southern pine beetle. This is because the lower altitude limit of the western yellow pine rises southward at the general average rate of about 400 feet to each degree of latitude; thus the influence of latitude is balanced by the influence of altitude. The variation in the time for the beginning or ending of the critical period between the lowest and highest altitude limits in any latitude is thirty to forty days or more, so that the application of the law to the determination of the time constants for different localities relates almost entirely to the variation in altitude.

In this particular species of insect we have to deal with an exceptionally wide range of departure from the time constant owing to its extreme sensitiveness to local influences affecting the temperature. Repeated observations at the forest-insect station at Ashland, Oregon, show that towards the higher altitude of the Siskiyou Mountains there is a marked retardation from the constant owing to the particular regional influences and the consequent slow melting of deep snows of some winters and, on the other hand, a remarkable acceleration in development and emergence on the south side of a tree as compared with the north side. In connection with observations on the seasonal phenomena of insects and plants at phenological stations located at intervals of approximately 500 feet, from the lowest elevation at 2,700 feet to the highest altitude at 5,700 feet, sections of bark infested with broods of the western pine beetle were taken from one tree near the lowest station and placed on the north side of a tree at each of the other stations. The results were exceedingly interesting and instructive as to the relation of altitude and exposure to the retardation and acceleration of the development and emergence of the insect.

Table I. shows the departures from the computed constant (*c*) in the average time of the three events in the developments of the broods in the bark placed on the north side of the trees as represented by first pupæ, first adults and first emergence.

TABLE I

VARIATION IN THE DATES OF EVENTS IN THE DEVELOPMENT OF BROODS OF THE WESTERN PINE BEETLE AT DIFFERENT ALTITUDES

Station No. (*a*)	Altitude (*b*)	Departure from Base Station 16		
		Computed Constants (*c*)	Actual (*d*)	Actual from Constant (*e*)
	Feet	*Days*	*Days*	*Days*
21	5,700	+25	+53	+28
20	5,200	+20	+36	+16
19	4,600	+14	+26	+12
18	4,200	+10	+19	+ 9
17	3,700	+ 5	+ 3	− 2
16	3,200	0	0	
15	2,700	− 5	−17	−12

Explanation.—*a*, station numbers; *b*, altitudes of stations; *c*, computed departures in days from the base; (+) = later, (—) = earlier than base date; *d*, averages of the departures in days from the average of the recorded base dates of first pupæ (February 20), first adults (April 20), and first emergence (May 16); *e*, departure of the actual from the computed.

This table shows (in column *e*) that there was an increasing intensity in the retarding influences from station 18 to 21 and that at station 17 there was a slight accelerating intensity of two days, while at station 15 there was an accelerating intensity of twelve days.

The observations were made in the spring of 1915 under the supervision of Mr. J. M. Miller, in charge of the forest insect station. Deep snow prevailed from stations 18 to 21 which was slow in melting, and this, as suggested by Mr. Miller, plainly accounts for the retarding influence. The accelerating influence at station 15 may be explained by the absence of snow and the fact that on the slopes of a mountain above a valley there is nearly always a warm or transition zone between the valley and the higher levels; the valley being cooler on account of the element of air drainage and inverted temperature, while the lower temperature of the higher levels above the warm zone is due to altitude. The results as shown in this table serve as a striking example of departures from the constant caused by local influences, what the influences are, and how the intensity is measured in terms of time as expressed in days.

In connection with the same series of experiments carried out in 1916 a large section of bark containing larvæ of the beetle was divided, one piece being placed on the north side of a tree and the other on the south side of the same tree. The records show that the development of the broods on the south side were in advance of those on the north side by 20 days for first pupæ and 35 days for first adults and first emergence, thus showing a remarkable accelerating influence on the south side as compared with the north side of the same tree. This represents an extreme case of divergence at the same place where the influences, except exposure, were identical. It also shows how exceedingly sensitive one species of insect may be to accelerating and retarding influences of temperature. This fact, therefore, must be taken into consideration in connection with the study of departures from the computed constant in the seasonal events of this species.

The Mountain Pine Beetle

The mountain pine beetle (*Dendroctonus monticolæ* Hopk.) is exceedingly destructive to the mountain or western white pine, the lodgepole pine, the sugar pine and less so to the western yellow pine. Whole forests of mountain pine, and especially lodgepole pine many square miles in extent, have been killed by it and a very large number of the finest sugar-pine trees of the Pacific Slope have been lost as a result of its destructive work.

Distribution.—The geographical distribution of the mountain pine beetle is not governed by that of a single host, as in the case of the western pine beetle, but by that of at least four species of pine. Thus its range extends throughout the pine zones of the Pacific Slope and into Wyoming, Montana and British Columbia, with a range of altitude from near sea level on the shores of Puget Sound to near timber line in the northern Rocky Mountains, and Cascades, to 10,000 feet or more in the southern Sierra Nevadas.

Number of Generations.—Normally there is only one generation annually. Toward its southern and lowest altitude range, however, there is a partial second generation and towards the highest altitude limit there is rarely time enough in the short season for the development of one generation in a year and there is evidence at hand to indicate that in some cases two or three years are required for the development of all of the broods of a single generation from the first eggs to the last beetles.

Control.—Owing to the slow development and late emergence of the broods of this beetle the critical period in which control operations can be carried on is much more extended than in the case of the southern pine beetle or the western pine beetle.

It is equally important, however, to know the limit of such a period for any given locality in order that the average date for the beginning and ending of the period for one locality may serve as a basis for computing the corresponding time constants for any other locality within the range of distribution of the beetle, except towards the highest altitudes where the overlapping of the broods of the one-, two- and three-year generations leave no choice as to taking advantage of a critical period.

The Pine Bark-Louse or Spruce Gall-Louse

A minute woolly plant-louse known as the pine bark-louse or spruce gall-louse (*Pineus strobi* Hrtg.) normally requires two species of host trees on which to complete its life cycle. One series of generations infests the bark of the trunks, branches and twigs of the white pine, and the other series of generations of the cycle infests the twigs and buds of the red spruce, causing the young twigs to develop into distorted galls which die and turn brown. In addition to the two generations which migrate from the pine to the spruce and back to the pine there is another form which continues on the white pine. Therefore, in localities where there is no red spruce it continues to develop on the pine.

Seasonal History.—The seasonal history of this insect is too complicated to be discussed in this connection; suffice it to say that the critical period in its seasonal activity on both the pine and spruce is when it is not protected by its covering of wax-wool on the pine or by the galls in which it develops on the spruce. This critical time is a short period after the young hatch and while they are moving about to find a location on the bark or in the opening buds.

Control.—It has been found that this and related species on other species of pine, spruce, larch and fir shade trees can be controlled by spraying the infested trees with kerosene emulsion or other contact insecticide, provided the application is made during the critical period of activity which is always coincident with the beginning of new growth on the infested pine and the opening of the buds on the spruce. This event varies with variations in geographical position, so that a calendar of date constants can be prepared to serve as a guide to the time to spray the trees in any locality. In this case, however, the beginning of growth on the pine and the opening of the buds on the spruce are alone reliable guides to the time to spray because the departures due to local influences need not be considered. No matter to what extent the accelerating or retarding influences may prevail in a given locality, they will affect alike both plants and insects.

Relation of Opening of Buds and Hatching of Chermes on Pike's Peak

Phenological records for the spring of 1916 at the forest insect station located at Colorado Springs, Colo., show that between Colorado Springs and timber line on Pike's Peak there is a close relation between the opening of the buds on the blue and Engelmann spruces and the hatching of the eggs of the gall-making *Chermes* that infests them, as shown in Table II.

It will be noted from Table II. that the recorded departures from the computed time constant for altitude at each station for both the spruce and the insect come well within the range of error. In other words, the number of days' departure from the constant are not sufficient to indicate that they are due to local influences. Therefore we can assume that during the spring of 1916 the general climatic conditions on Pike's Peak were about normal and that, unlike the results as shown in Table I., the facts conform with the altitude factor of the law.

Table II. shows not only a remarkably close agreement with the altitude time constant average of one day to 100 feet within an altitude range of 5,500 feet, but that a close relation between the periodical events of the opening of the buds on the spruce and the hatching of the eggs of the insects is maintained at all stations, being the same at the three higher stations but slightly different at the two lower stations.

TABLE II

VARIATION IN THE DATES OF OPENING OF THE BUDS ON SPRUCE AND THE HATCHING OF EGGS OF THE SPRUCE GALL-LOUSE (*Chermes* sp.) AT DIFFERENT ALTITUDES OF PIKE'S PEAK. FROM RECORDS BY POLLOCK.

		Spruce			Chermes			
Stations (*a*)	Altitudes (*b*)	Constant (*c*)	Recorded (*d*)	Departures (*e*)	Constant (*c*)	Recorded (*d*)	Departures (*e*)	(*f*)
	Feet	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	
7	11,500	+55	+51	−4	+55	+48	−7	0
6	10.500	+45	+43	−2	+45	+40	−5	0
5	9,500	+35	+37	+2	+35	+34	−1	0
4	8,500	+25	+26	+1	+25			
3	7,500	+15	+19	+4	+15			
2	6,500	+ 5	+ 1	−4	+ 5	+ 3	−2	+5
1	6,000	May 8	May 8		May 11	May 11		+3

Explanation.—*a*, the number designations of the stations; *b*, the altitude of each station; *c*, the time constant in days computed from the base-station date; *d*, actual departures in days from the base date (May 8) for opening of the buds on the spruce and from May 11 for the hatching of the eggs of *Chermes*; *e*, departure of the actual (*d*) from the computed constant (*c*); *f*, difference between the departures for opening buds and hatching of eggs; (—) = days earlier and (+) = days later. The table is based on records made by J. H. Pollock, scientific assistant, who is making a special study of the *Chermes* of the Rocky Mountains.

The Hessian Fly

The distribution, seasonal history, and general methods of control of the Hessian fly are so well known that it is not necessary to discuss the details in this connection, except in so far as they relate to the application of the law to the investigation of the so-called fly-free dates for sowing winter wheat to avoid damage by the autumn generation and consequent further damage by the spring generation.

The critical period in the seasonal history of this great menace to wheat culture, during years when and in localities where it occurs in destructive numbers, is the period of its emergence in the fall. This, like all other periodical events of the seasons, is controlled primarily by climatic conditions and secondarily by the weather and local soil and topographical influences. The climatic influence is more or less constant, except in seasonal variations, while the other factors contribute to departure from the average.

It is generally recognized that if wheat is sown just at the close of the period of general flight of the fly, the danger of serious injury to the wheat before the following spring will have passed by the time the wheat is above the ground and exposed to attack. Therefore the problem that has claimed the attention of wheat growers and economic entomologists is how to determine and select the fly-free date for different localities and sections of the country, and for an average season. It would now seem that the problem is in a fair way of being solved through the application of the bioclimatic law in its investigation.

When the average fly-free date as determined by Webster for Wooster, Ohio, is taken as a basis for computing corresponding fly-free date constants for any other locality within the entire region of winter wheat culture in the United States, where the fly is or has been present, and when it is compared with the average dates that have been found in actual practise to be safe, the earlier or later departures from the constants are found to be within the range of error and the departure due to regional, local and seasonal influences. It is also found that the general influences and the general intensity of these influences can be determined by further investigations and so measured in terms of time that the computed constant can be corrected for any locality so as to be close enough to the actual to answer all practical purposes.

The preceding examples of research problems will suggest the application of the law to any line of entomological research that involves a consideration of geographical distribution, variation in seasonal history, and the best time to apply remedies under variations in geographical position.

RELATION OF THE LAW TO FARM PRACTISE

Any periodical farm practise conducted during the spring, summer or autumn which involves a more or less limited period in which the work must be begun and completed is controlled by the same laws as those which control the beginning, advance and ending of the seasons, and the consequent periodicity of animal and plant activities. Therefore a given periodical practise is subject to the same rate of variation in time with variations in geographical locations as that of the periodical events in the plants and animals involved in the practise. Consequently periodical farm practise in general is subject to the application of the law in its study and proper adjustment to geographical requirements for the attainment of the best results.

Some of the problems in farm practise which have a direct relation to the bioclimatic law are:

(*a*) Seedtime and harvest, as applied to a wide range of farm, garden and truck crops, and as adapted to the varying climatic conditions which prevail from the lowest to the highest latitudes and altitudes and from eastern to western longitudes of the United States.

(*b*) The application of remedies against insect pests and plant and animal diseases.

(*c*) The selection of varieties of domestic animals and cultivated plants and the types of agriculture best adapted to regional and local conditions of soil, climate, etc.

Under problems *a* and *b* there are more or less definite periods in which the work must be done to attain satisfactory results. Each period for a specified farm practise is limited to the earliest and latest dates that are permissible under various requirements of the season, weather, etc. Between these limits there is an optimum or *best time* to do the work to secure, other things being equal, the best results and this will vary with different geographical regions and positions and with different seasons, local weather conditions, etc. Heretofore there have been no reliable guides to the selection of this best time.

Some farmers in nearly every farming community are guided by the changes in the moon, the signs of the zodiac, etc., while some are guided by long experience and observations and consciously or unconsciously approximate closely the best time. The faith in astronomical events and signs is evidently based on occasional successes from chance adoption of the best time which coincided with some astronomical event, the successes being remembered while failures or poor successes at other times when the same guides were followed, were forgotten or charged to some adverse condition. That a given "change in the moon" or a sign in the zodiac can not apply to an extensive range of latitude or altitude is clearly apparent when it is considered that the generally recognized time to do certain farm work, such as the planting of corn, etc., varies a month or more between a southern and a northern section of the country or between valleys and adjacent high mountain plateaus.

Therefore, it is in the general designation of the best time to do the more important periodical farm and garden work in any section of the country, and in the utilization of coincident events in native trees and shrubs as guides to the departures in any season and locality, that the application of the principles of the bioclimatic law can perhaps render its greatest service to American agriculture.

The importance and value of the law in the designation of dates and periods for various farm practises applicable to different parts of the country appear to have been demonstrated in the results of our study of over 40,000 reports of wheat growers as to the beginning, general, and latest seeding and harvesting dates for winter wheat in nearly every county in the country where winter wheat is grown as a regular crop.

The tabulated results of these studies as in the example of West Virginia[1] show that between the county averages of the reported dates and the computed date constants for the same counties and events there was in most cases a difference of only a few days, except in regions and sections of the country where there is a general accelerating or retarding influence to cause decided departures.

The tabulated averages of the reported dates of the beginning of wheat harvest are of special interest and significance because the periodical event of the ripening of wheat and the beginning of harvest is controlled entirely by the climatic and other factors associated with geographical position except in so far as the beginning of harvest after the wheat is ready to cut is delayed by weather conditions or arrangements for machinery or help.

The averages of reported seeding dates are much less reliable because of their modification by the customs and conveniences of the growers of each community.

From these tabulated data on seeding and harvest of wheat, and by the aid of the geographical and time coordinates of the law, wheat-seeding calendars were prepared for all of the states and the entire country to show the date constants and periods of the general average *best* and *safest* time to sow winter and spring wheat. Other calendars were prepared to show the date constants on which wheat may be expected to ripen and be ready to harvest for any locality within the range of culture. Maps were also prepared with guide or isophanal lines (lines of equal bioclimatic phenomena at the same level) by means of which the proper date constant of the calendar could be found for any county or locality. In addition the average regional and state departures were shown on the maps to indicate the required correction of the date constant to approximate more nearly the actual average date.

It is significant as to the possibilities of the application of

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[4] Supplement 9, *Monthly Weather Review*, 1918, p. 15.

the bioclimatic law in working out calendars for all periodical farm practises that it has been successfully accomplished in a broad general way in the case of seedtime and harvest for winter and spring wheat.

Geographical Adaptation

The proper selection of the kinds of domestic animals and cultivated plants or the type of agriculture best adapted to regional and local climatic and other conditions is of primary importance in the interest of progressive and prosperous agriculture. The relation of the law to these problems is the same as that to seedtime and harvest because the climatic conditions best adapted to various farm crops conform to the same law as that which governs the periodical phenomena of the animals and plants involved. Therefore, knowing the conditions as to altitude, latitude and regional climate under which a given kind of farm crop or type of farming succeeds best, it is possible by means of the time, altitude and latitude constants of the law to indicate the locations of other places where similar favorable conditions will be found so far as the climate is concerned. In like manner it would be easy to define the regions and sections of the country where the climatic conditions would be unfavorable. By this method it could have been predicted, long before it was determined by the slow and expensive process of experiments and practical experience, that certain crops could or could not be grown in Alaska.

In connection with the study of the reported dates of wheat harvest, it was found that the latest dates of harvest at the higher latitudes and altitudes and that the earliest dates at the lowest latitudes or altitudes, together with the periods between seeding and harvest, served as a reliable basis for tracing the latitude and altitude limits of winter wheat culture and the intermediate optimum zone where, other things being equal, it would succeed best.

A like study of spring-wheat data furnished evidences and facts as to the latitude and altitude limits of spring-wheat culture and the optimum zone where it should succeed best. The range and optimum thus determined not only included the areas where spring wheat is grown extensively, but indicated that there are areas of considerable extent farther east and south where spring wheat may be grown successfully, and subsequent experiments have furnished additional evidence that this is true.